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14. ABSTRACT
The Air Force Research Laboratory developed monopropellant, AF-M315E, has been selected for demonstration under the NASA sponsored Green Propellant Infusion Mission (GPIM) program. As the propulsion system developed by Aerojet-Rocketdyne for this propellant advances in maturity, studies have been undertaken to address the knowledge gaps in the adiabatic compression sensitivity of the propellant as it relates to the system parameters for this mission. Of particular interest is the sensitivity of the propellant at elevated temperatures and the resulting system peak pressures and dynamic response characteristics. For this study, an adiabatic compression U-tube apparatus was used to determine the driving pressure threshold levels of the propellant at elevated temperatures. These tests simulate the worst-case scenario resulting from a rapid closure or opening of valves in a propellant feed line *in situ*. The results of these tests are presented as a preliminary assessment on the margin of safety for the propellant.

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Adiabatic Compression Sensitivity of AF-M315E

AIAA Propulsion and Energy Forum
July 27, 2015

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ERC, Incorporated
Air Force Research Laboratory
Edwards AFB, CA

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Outline

- GPIM Mission
- Background
- Experimental methods
- Results
- Conclusions

GPIM Team

GREEN PROPELLANT INFUSION MISSION

ll Aerospace
- Program Lead – PI
- Mission System Engineering
- Mission requirements
- Flight thruster performance verification
- Ground and flight data review
- BCP-100
- AI&T
- Launch and Flight Support

Aerojet Redmond Operations – Co-I
- Propulsion payload
- 1N and 22N thruster development
- Payload integration
- Ground and flight data review

NASA MSFC
- Contracts Office

NASA GRC – Co-I
- Plume modeling
- Ground and flight data review

NASA KSC
- Launch Services Support

Air Force SMC
- Mission Operations
- Ground Segment Support
- STPSat GSE

AFRL Edwards – Co-I
- Propellant (contribution)
- Propellant loading cart (contribution)
- Propellant loading
- Ground and flight data review

Ball assembled a cross-cutting team of US experts for GPIM

Background

- Rapid isentropic compression of entrained gas bubbles
  - Closure or opening of valves
  - External mechanical shock
- Gas introduced by thermal decomp., during priming, or high Q pumping
- Bubble collapse increases local temp. & exothermic decomp.

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

T = Temperature [K]
P = Pressure [psi]
γ = ratio of specific heats

Purpose of Study

- Pressure/temperature threshold initiation levels
- Sensitivity of thermally damaged propellant
  - Thermal soak-back from cat. preheat
- Characterize dynamic response
- Waterhammer effect

AF-M315E Formulation

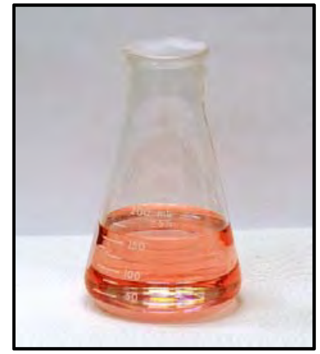
AF-M315E Monopropellants Produced From Energetic Ionic Liquids

$[HOCH_2CH_2N_2H_4]^+ [NO_3]^-$

Hydroxyethylhydrazinium Nitrate (HEHN)

$[NH_3OH]^+ [NO_3]^-$

Hydroxylammonium Nitrate (HAN)



Properties	AF-M315E	Hydrazine
Isp_{vac} [lbf-sec/lbm] *(e = 50:1 Pc = 300 psi)*	**266 (theo.) 250 (del.)**	**242**
Density [g/cc]	**1.465**	**1.021**
Vapor Pressure [torr]	**< 0.1 (w/o H_2O)**	**14.3**
Melt point [^oC]	**< -22**	**1**

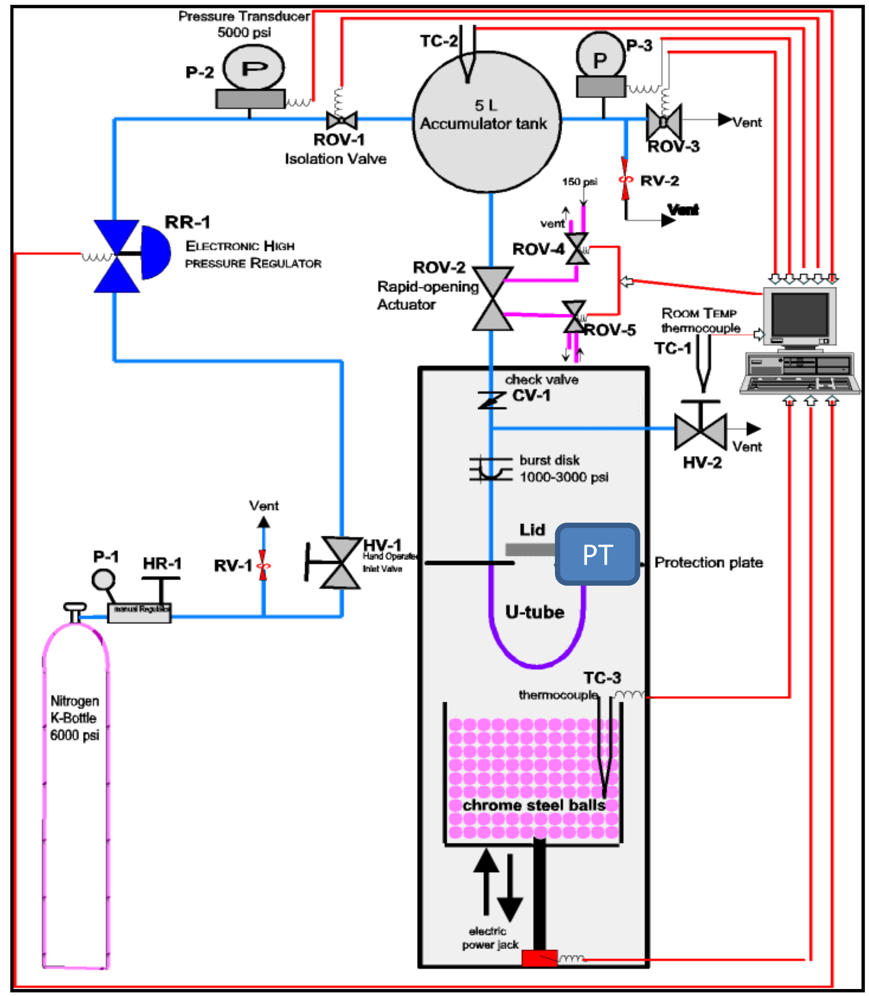
Safety Characteristics

Characteristic	Results
Thermal stability	0.43% weight loss per 24 hours at 75 ^{O}C
Unconfined ignition response	No explosive response
Impact sensitivity [Olin Mathiesen drop weight]	60 kg-cm
Friction sensitivity [Julius Peters sliding friction]	300 N
Detonability [NOL card gap at 0 cards]	Negative (< 24 cards)
Electrostatic discharge sensitivity	Insensitive to static spark discharge (1J)
Vapor toxicity	Low hazard (No Self-Contained Breathing Apparatus)
Vapor pressure	< 0.1 torr

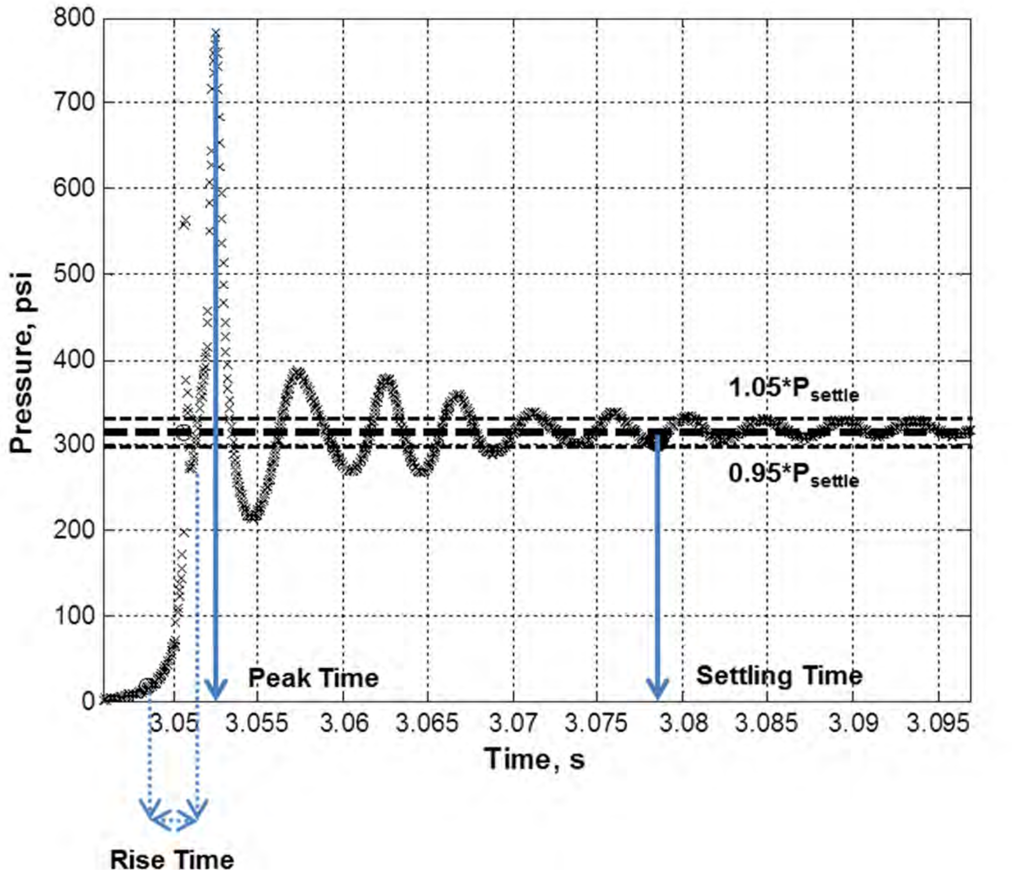
Procedure and P&ID

Procedure

- 3 mL in Ti-3Al2.5V U-tube
- Tube immersed in bath for 20 minutes
- Fast pressurization (GN2) with burst disc
- Compression rates of 80k to 140k psi / second
- LabView sampled at 25 kHz for 5 seconds



MATLAB Characterization



Terminology

- Max Pressure
- Settling Pressure
- Peak Time
- Rise Time
- Settling Time
- Compression Rate

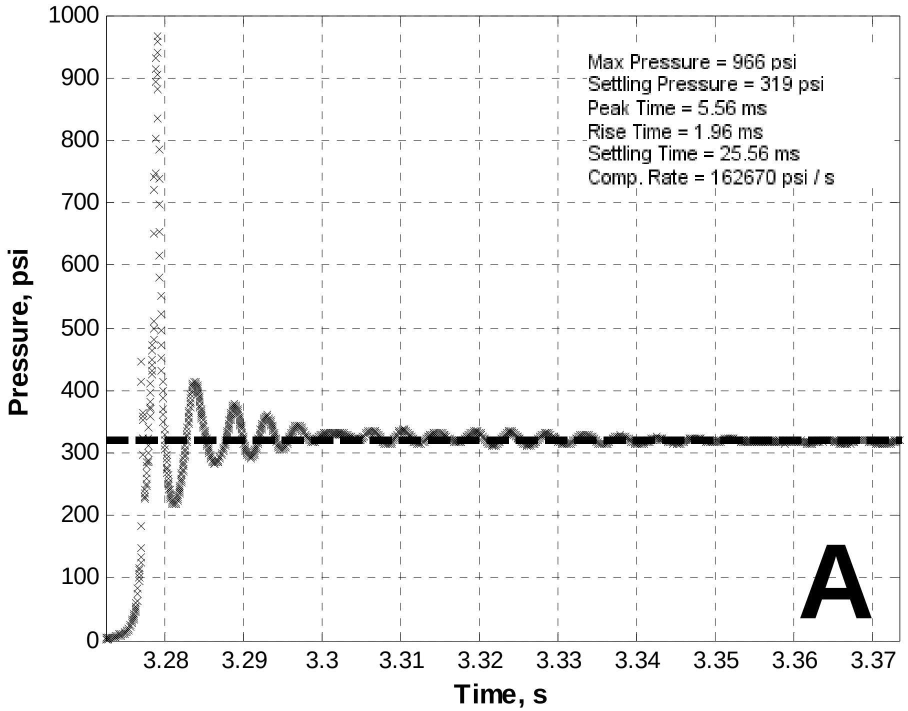
Summary of AF-M315E Adiabatic Compressions

Temperature [°C]	Pressure [psi]	POS	NEG
25	300	0	19
25	350	2	8
25	400	3	1
25	500	1	0
25	1500	1	0
60	300	0	8
90	300	0	21
90	350	1	0
90	400	1	0
100	250	0	19
100	300	1	0
100	400	1	0

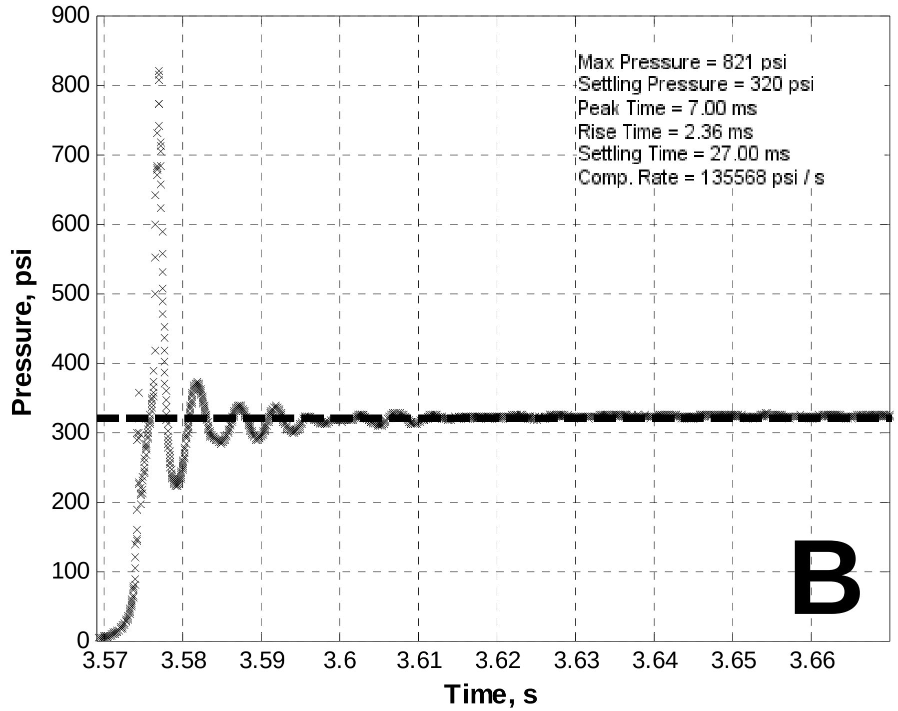
Waterhammer Effect

$$f_n = \frac{1}{2\pi}\sqrt{\frac{K}{W}}$$

f_n = undamped natural frequency [Hz]
K = bulk modulus [psig]
W = weight [lb]

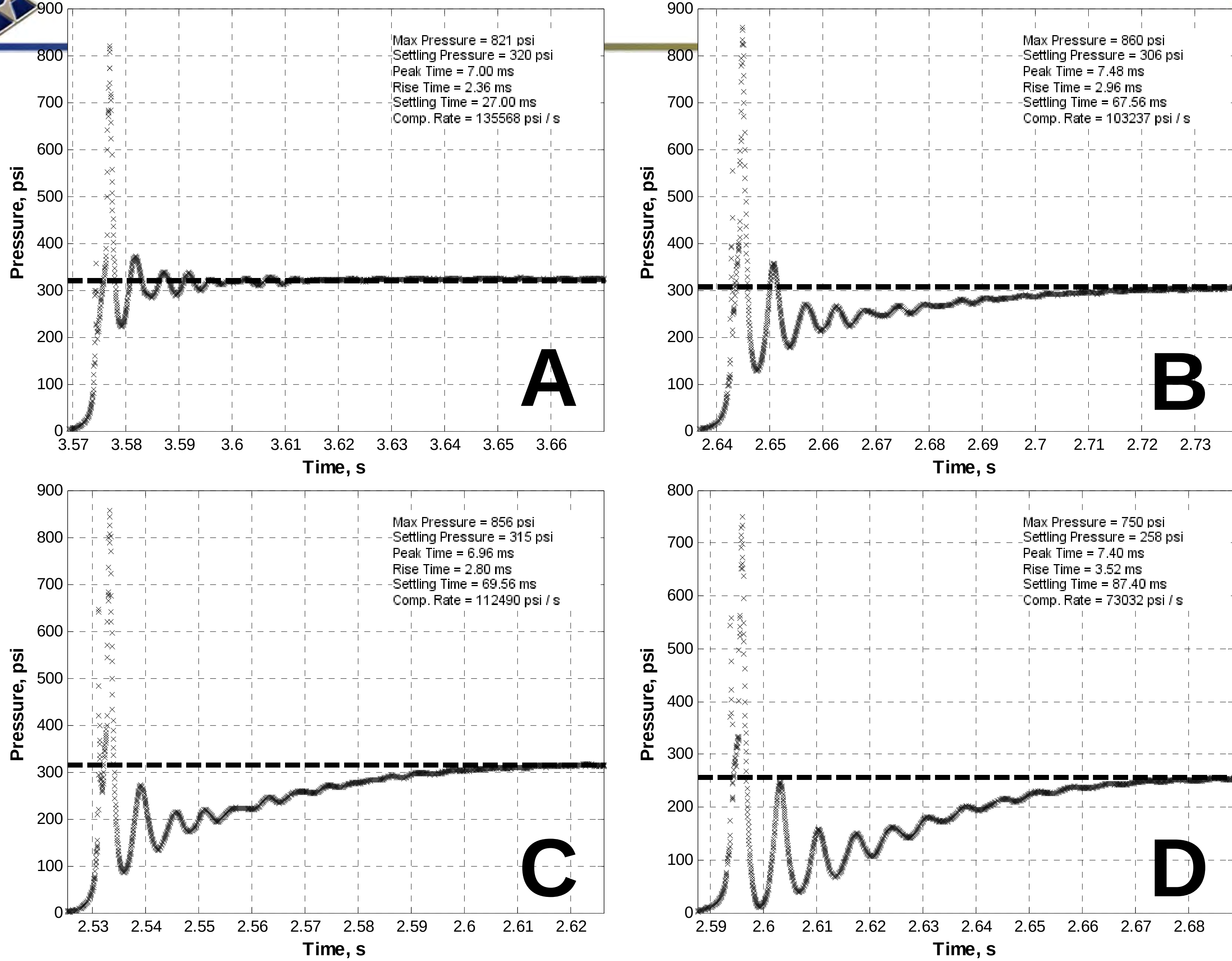


K = 2.2 x 10^9 Pa

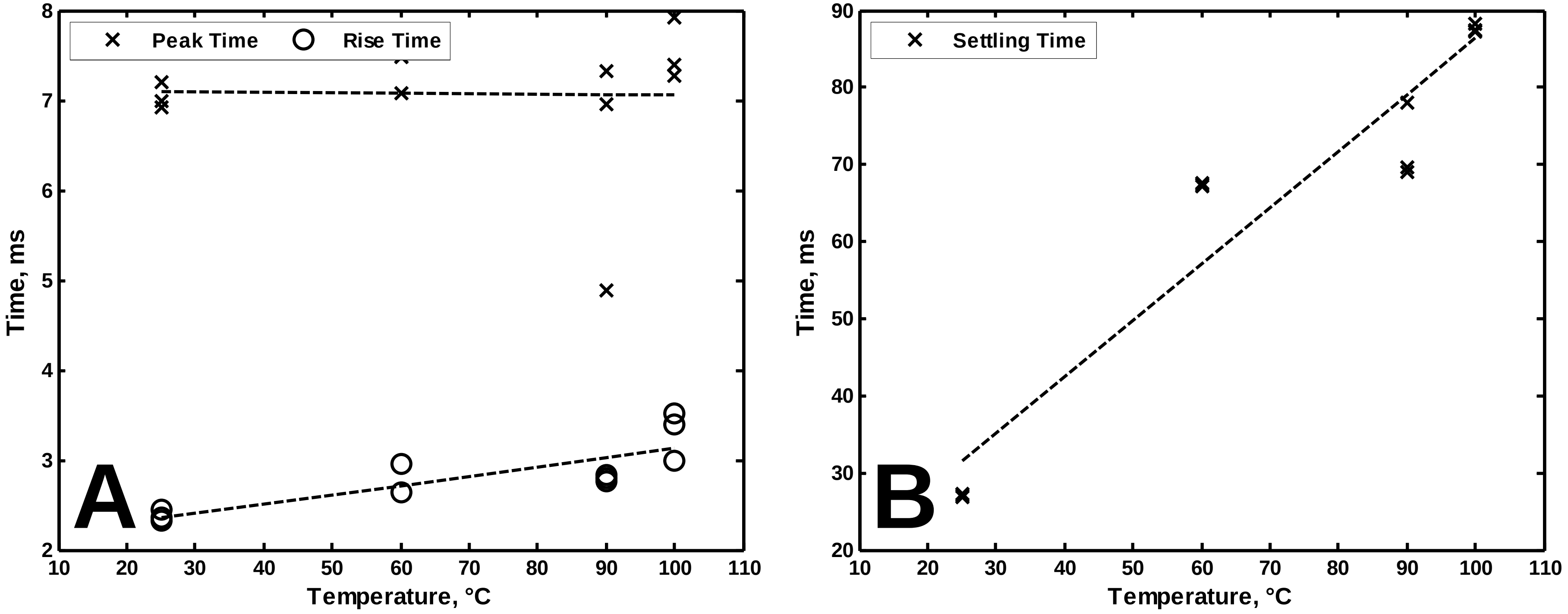


K = 5.7 x 10^9 Pa

AF-M315E Adiabatic Compressions



Characteristic Times



Parameter Averages

Parameter	Water	AF-M315E			
	300 psi	300 psi			250 psi
	25 °C	25 °C	60 °C	90 °C	100 °C
Maximum Pressure [psi]	797	829	840	833	718
Settling Pressure [psi]	313	318	314	313	253
Peak Time [ms]	5.41	7.04	7.35	6.39	7.53
Rise Time [ms]	2.04	2.37	2.75	2.80	3.31
Settling Time [ms]	28.75	27.04	67.37	72.23	87.61
Compression Rate [psi / s]	153805	133916	114932	111852	76667
Est. Adiabatic Temp. [°C]	--	444	526	597	568

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

T = Temperature [K]
P = Pressure [psi]
γ = ratio of specific heats

Summary

- No positive responses at:
  - 300 psi, 25 °C to 90 °C
  - 250 psi, 100 °C
- Bulk modulus explains dynamic behavior
- Peak pressure not largely dependent on temperature
- Peak and rise time not functions of temperature
  - Settling time drastically increased with temperature

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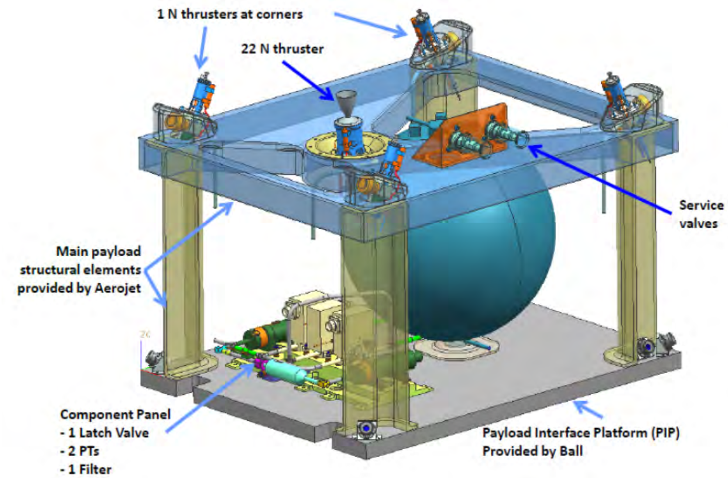
Hazards of Thermally Damaged Propellant



<u>Thermal Management of 5-lbf Thruster is Problematic</u>

- Thermal soak back from catalyst pre-heat operations causes the thruster propellant valve and propellant to heat

- AFRL to test hazards of heated propellant in contact with titanium to determine a maximum safe temperature (30 minutes)

- Primary concerns are adiabatic compression and impact sensitivity

- Aerojet to provide all test materials needed under the CRADA such as heating mantles and burst discs to allow testing in titanium to simulate valve seat material and system tubing

AFRL conducting adiabatic compression on propellant heated in situ to determine an acceptable temperature and driving pressure for safe operation

<u>Ruptured Steel U-Tube</u>